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Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 19, NO. 3, PP. 99–103
FIGS. 1–2, DECEMBER, 1949

RED BED COLORATION[1]

GEORGE L. ROBB[2]
Golden, Colorado

ABSTRACT

Samples of red beds of the Permo-Pennsylvanian Maroon formation were studied to determine the constituents contributing to the coloration and the relationship of those coloring constituents to the associated mineral grains in the rocks. These samples were of two main types: fine- to coarse-grained, red-colored, micaceous, arkosic sandstones; and red-colored, micaceous shales. Microscopic study disclosed a close association between a red material, which was identified as hematite by x-ray analysis, and a micaceous mineral which by x-ray analysis was found to be either muscovite, illite, or a transitional mineral whose composition ranged between the compositions of muscovite and illite. The composition of this transitional mineral depends upon the degree of alteration of the biotite from which it originated. The hematite occurs mainly between the lamellae of the micaceous material. This hematitic material fills the interstices of the arkoses and makes up the bulk of the red shale. The alteration of the biotite took place after deposition.

INTRODUCTION

This study had two objectives: (1) to determine the constituents contributing the red color in red bed formations and (2) the relationship of those constituents to the associated minerals in the rocks. The present investigation was based on observations and analyses of the Maroon formation from the Gore Range of Colorado, but conclusions are reached that may be applicable to other occurrences.

The literature abounds with attempts to explain the coloration of red beds. Most authors agree that the color is caused by some compound of iron. An average iron content of 6.16 per cent in four typical red shales and one red sandstone was determined in analyses quoted by Mathews and Grasty (1909). However, Dorsey (1926) quotes an average of six per cent ferric oxide in three normal non-red shales. Tomlinson (1916) has summed up a number of analyses in which red and purple slates had a higher ferric oxide content than did green and black slates. Tomlinson further quotes analyses which showed that a number of red shales and sandstones contained a higher proportion of ferric oxide than ferrous oxide and that the reverse held true for green shales and sandstones. Dorsey (1926) sums up the color for various oxides of iron as follows: ferrous oxide, FeO, green; ferric oxide, $Fe_2O_3 \cdot nH_2O$, color ranges from yellow for limonite to red for hematite. The presence of iron does not alone make sediments red; the iron must be in the form of hematite or possibly of turgite.

A chemical analysis of a green shale from the Maroon formation, made during the present study, showed 3.63 per cent ferric oxide although an x-ray analysis disclosed no hematite. Thus, some of the ferric iron in green sediments may be present as one of the non-red oxides or as a constituent of another mineral. In the above case the iron may be contained in the mineral illite.

Red sandstones have been described in which the coloring material is free hematite occurring interstitially as well as coating the quartz and feldspar grains. However, most authors ascribe the color to ferruginous or red clay. The term *red clay* is preferable because all ferruginous material is not red.

[1] Read before the Denver meeting of the Association, April 28, 1948.

[2] Geologist, U. S. Bureau of Reclamation.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to Dr. F. M. VanTuyl, Colorado School of Mines, under whose direction this study was undertaken. Roger Rhoades, Chief Geologist, U. S. Bureau of Reclamation, has contributed editorial assistance. Dr. N. C. Schieltz, U. S. Bureau of Reclamation, made the x-ray diffraction analyses.

LOCATION AND DESCRIPTION OF SAMPLES

Samples from the Maroon formation, Permo-Pennsylvanian in age, were collected from outcrops along the Vail Pass highway on the western slope of the Gore Range in mid-western Colorado. The Maroon formation in this area is composed predominately of dark-red sandstones and red or purplish thin-bedded shales. The sandstones grade into conglomerates in some places. The sandstones are coarse-textured arkosic rocks with a red cementing material. A few massive limestone beds ranging from 15 to 60 feet in thickness form bold outcrops. The seven samples collected represent a stratigraphic section of about 500 feet in the middle third of the Maroon section.

Two general types of samples were collected. One type is a red-colored, micaceous, arkosic sandstone. The four samples of this type range in grain size from fine-grained to a pebble conglomerate. The ferric oxide content ranges from 2.79 per cent in the fine-grained rocks to .67 per cent in the conglomerate. The ferrous oxide content averages about .60 per cent in all samples. The second type of sample is a micaceous shale. Of the three samples of this type, two are red and one is green. The red shales have an average ferric oxide content of seven per cent and an average ferrous oxide content of one per cent. The green shale, which occurs as a stringer in the red shale, has a ferric oxide content of 3.63 per cent and a ferrous oxide content of one per cent.

The arkosic samples are petrographically similar, differing mainly in grain size. The predominate minerals are quartz, orthoclase, microcline, plagioclase (oligoclase), biotite and muscovite. These minerals indicate that the source rock for these sediments was a granite or a granite gneiss. Some of the feldspars are sericitized, but no profound alteration exists. Flakes identified as original muscovite are unaltered. Biotite flakes commonly show incipient alteration to a red material believed to be hematite. The samples possess interstitial matter which is red and semi-opaque having the appearance of hematite, but more precise observation reveals this material to be a platy or micaceous mineral (or minerals) with hematite occurring between the lamellae.

When the altered biotite flakes were crushed with a needle and observed with a binocular microscope the hematite was found to lie between the lamellae. An occasional biotite flake is altered on one end and apparently is unaltered on the other. The altered biotite is soft and easily broken and does not have the resilience common to unaltered biotite or muscovite. The plates or lamellae which make up the bulk of the interstitial matter in the arkoses have the same appearance as the altered or bleached biotite grains which occur as a part of the granular constituents of the sediment.

The red shales are composed mainly of the same type of material that makes up the interstitial matter in the arkoses. The minute flakes of micaceous material are altered incipiently to a red color similarly to the larger biotite flakes in the arkoses. The green shale contains little unaltered biotite.

The finer fractions resulting from disintegrating and screening the original samples have about the same intensity of color regardless of the grain size of the original rock. The larger grains have very little coloring material adhering after the screening process. The color intensity of the finer fractions and the lack of color adhering to the larger grains indicates that the color of the sediments is mainly associated with the interstitial material.

All of the red color in the samples was

removed by a 30 minute immersion in warm HCl; no hematitic material could be found between the lamellae of any of the micaceous material after the acid treatment. No other significant change in the constituent mineral grains or the micaceous material of the interstitial matter resulted from the immersion in acid.

X-RAY ANALYSIS

The interpretation of x-ray data is extremely difficult when the sample contains more than three or four separate minerals. With this in mind the samples for x-ray analysis were selected by hand with the aid of a binocular microscope.

The first sample tested by the x-ray diffraction method consisted of the red-colored platy material which makes up the interstitial matter in the arkoses and the bulk of the red shales. The resulting x-ray pattern indicates that the platy material is a mineral with a crystal structure transitional between the crystal structures of muscovite and illite. The pattern does not indicate that the material is a mixture of muscovite and illite but rather is a mineral whose composition is somewhere between the composition of these two minerals. The x-ray pattern contains characteristic lines pointing to the presence of hematite in the sample.

The second sample analyzed by x-rays was made up of biotite flakes with red material between the lamellae. Biotite and hematite were the only minerals whose patterns were identified on the x-ray film.

A sample was made up of clear flakes which had a minor amount of red coloring, excluding the uncolored material which had the appearance of original muscovite. Hematite was not present in sufficient quantity to be revealed by the x-rays.

The next sample was taken from the green shale. Illite was the only mineral present. This sample had a ferric oxide content of 3.63 per cent by chemical analysis yet no hematite was indicated on the x-ray pattern.

The last sample consisted of a red material which was scraped from the larger pebbles of the conglomerate. The x-ray pattern implied that the material was again a muscovite-illite transitional mineral and hematite.

The red shale samples were not suitable for x-ray analysis because of the high percentage of biotite, feldspar and quartz grains. The similarity of this material to the red matrix of the arkosic samples, as observed under the microscope, suggests that the same type of alteration has taken place in the shales as well as in the arkoses.

The biotite is being altered by substitutions in the crystal structure, thus the characteristics of the biotite are changed to those of the present mineral. The process by which these substitutions take place is not clearly understood although the end results have been observed by x-ray analysis.

Pauling (1930) considered mica minerals in general to be made up of layer lattices which consist of two tetrahedral silica sheets with a gibbsite or brucite sheet between. Later work by Hofmann, Endell and Wilm (1933) showed the montmorillonite clay structure to be similar to that of the micas. Their schematic presentation of the structure of montmorillonite is shown in figure 1.

The structure of illite is similar to that of montmorillonite except that about 15 per cent of the Si^{4+} ions in the tetrahedral sheets are replaced by Al^{3+} ions with the resulting excess charge being satisfied by K^{+} ions between the silica sheets of successive units. Grim, Bray and Bradley (1937) present the structure of illite shown in figure 2.

The structure of muscovite is similar to the structure of illite as suggested by Pauling (1930) and confirmed by Jackson and West (1930). In muscovite 25 per cent of the Si^{4+} positions in the tetrahedral sheets are occupied by Al^{3+} ions, together with a central gibbsite sheet. The number of K^{+} ions is proportionately greater.

Phlogopite which is a magnesium bio-

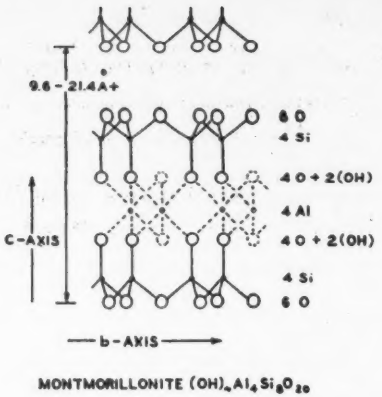

FIG. 1.—Schematic presentation of crystal structure of montmorillonite. (After Hofmann, Endell, and Wilm.)

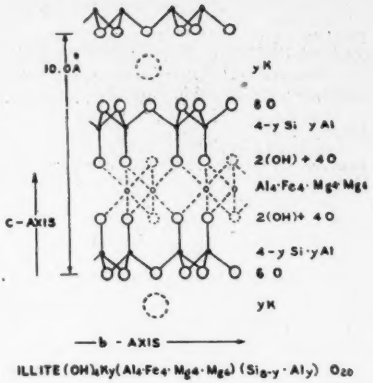

FIG. 2.—Schematic presentation of the crystal structure of illite. (After Grim, Bray, and Bradley.)

tite has the same structure as muscovite in the tetrahedral sheets with a central brucite sheet instead of a gibbsite sheet. The iron bearing biotites have alumina, ferrous and ferric iron substituting for magnesium in the brucite sheet.

Therefore, the mica group can be considered as an isomorphous series with ion substitutions in both the outer silica sheets and the center gibbsite or brucite sheets being possible. The difference between the various mica minerals is in chemical composition, amount and location of the ion substitutions.

The substitution present in the samples described seems to have been twofold. The alteration mineral identified is a transitional mineral somewhere between muscovite and illite. It would seem then that the percentage of alumina in the outer silica sheets is between 15 and 25 per cent. Also part of the iron, which is converted to hematite, has been withdrawn from the center sheet of the biotite crystal lattice, being replaced by alumina. The alumina may have come from the outer sheets with silica being drawn in from outside solutions.

CONCLUSIONS

From the evidence presented, the conclusion may be drawn that hematite is the mineral forming the red color in the samples of Maroon sediment. The hematite commonly lies between the lamellae of an alteration product of biotite whose composition ranges between that of muscovite and that of illite. This muscovite-illite transitional mineral apparently has been formed by substitutions in the biotite crystal lattice. Iron, which is oxidized to hematite, has been withdrawn from the central sheet of the biotite crystal lattice and replaced by alumina. This new mineral from all appearances is too soft to have withstood much transportation and still retain its large grain sizes. This indicates that at least part, if not all, of the alteration took place after deposition.

Individual particles of the red shales after disintegration exhibit the same characteristics as the altered biotite flakes and the interstitial material in the arkoses, indicating that the original shale material was highly micaceous. The color of the green stringer may be explained as resulting from a local reducing condition or as ferric iron in the structure of the mineral illite.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 19, NO. 3, PP. 104–111
FIG. 1, DECEMBER, 1949

MINERALOGY OF THE CHELTENHAMIAN BEDS AT BEAUMARIS, VICTORIA

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ABSTRACT

The mineralogy and mechanical composition of fine grained clayey sandstones of marine origin in the type Cheltenhamian section at Beaumaris, Victoria, are described. The beds have approximately the same grain size through about 40 feet of vertical cliffs. The minerals present indicate an origin from the erosion and sorting of previous sedimentary rocks. The clay mineral present has been identified as nontronite.

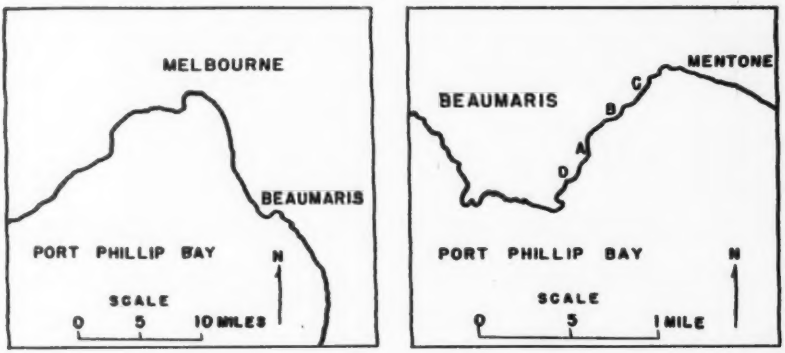
INTRODUCTION

The earliest account of the beds forming cliffs on part of the eastern side of Port Phillip Bay (figure 1), particularly at Beaumaris, is that of Hart (1893) who recognized their Tertiary age and described what was later to become the type section of the Cheltenhamian beds. He also recognized that the beds were folded into gently dipping pitching anticlines and synclines with the axes approximately north-south. It was later shown that the cliffs at Beaumaris were formed from an eroded monoclinal fold (Hills, 1940).

The Cheltenhamian beds (as described by Hart, 1893) consist essentially of the following members (oldest at base):

Sand, upper; loose white sand with Recent shells.
Coarse sand, lower; gray, white, yellow or red.
Ferruginous sandstones with ironstone bands; about 70 feet thick, and unfossiliferous.
Ferruginous sandstone and marl; fossiliferous.

Hall and Pritchard (1897) described these beds and stated that they were of Miocene age and probably derived from the redistribution of material from Silu



a b

FIG. 1.—(a) Map showing location of the area of study. (b) Localities of sections A, B, C, and D described in the text.

rian rocks. At the base of the ferruginous beds they noted a thin bed containing "teeth, bones and iron-stone concretions which will probably be found to mark the junction of the two formations, the Eocene beds occurring below it." The fossil commonly seen in the lower part of the ferruginous beds is an Echinoderm, *Lovenia forbesi*, which occurs in large numbers in certain horizons.

Singleton (1941, p. 32) proposed the name Cheltenhamian stage for the fossiliferous ferruginous sandstones of the lower part of the coastal cliffs and the underlying "nodule bed" at Beaumaris, near Cheltenham, Victoria.

Crespin (1943, p. 64) regards the section at Beaumaris as basal Kalimnan (lower Pliocene), Singleton's Cheltenhamian stage (upper Miocene) being considered as a facies of the Kalimnan and not as a separate stage. The term "Cheltenhamian beds" is used in this paper for the section of the Tertiary beds exposed in the cliffs at Beaumaris.

Singleton (*op. cit.*) has described in detail a number of sections of the Cheltenhamian beds at the positions shown in figure 1. Lithologically the beds above the nodule bed appear to be similar although Singleton has confined the name Cheltenhamian to the ferruginous sandy marls containing fossils.

The samples described here were obtained from the Cheltenhamian and overlying ferruginous sandstone (Hart's no. 2) from Singleton's locality B (*op. cit.*, p. 33) and elsewhere from these beds at Beaumaris. The section at B consists of:

(d) 8 feet white sands
(c) 19 feet ferruginous sandstone with hard bands
(b) 17 feet pale fine sandstone or sandy marl
(a) 3 feet brown sandstone with shells near low water mark

47 feet (total thickness)

The nodule bed is just below this, and the Cheltenhamian includes (a) and (b) together with the nodule bed. Samples were collected at the following positions from beds (b) and (c) in this section:

(d) white sands

---

massive ferruginous sandstone
ironstone band
sandstone
ironstone band
(c) (5) sandstone
ironstone band
sandstone
thin bed of coarse quartz and ferruginous cement
(4) sandstone
thin bed of coarse quartz and ferruginous cement

---

(3)
(b) (2) fine-grained yellow-brown sandstone or marl with little differentiation
(1)

(a) brown sandstone with shells at low-water mark.

Table 1 gives a list of the samples collected from the various localities.

TABLE 1

Sample No.	Section[1]	Description	Position in bed (after Singleton)
1	B	yellow-brown fine sandstone	b
2	B	yellow-brown fine sandstone	b
3	B	yellow-brown fine sandstone	b
4	B	ferruginous sandstone	c
5	B	ferruginous sandstone	c
6	C	ferruginous sandstone	c
7	C	white sandstone	d
8	D	ferruginous sandstone	b
9	A	beach sand	—
10	—	white sandstone, lower	Mentone
11	—	white sandstone, upper	Mentone

[1] Position of sections is shown in figure 1.

The distribution of the samples examined is therefore:

	Samples
Cheltenhamian beds (as defined by Singleton)	1, 2, 3, 8
Ferruginous sandstone with iron stone bands, conformable with the Cheltenhamian	4, 5, 6
White sandstone conformably overlying the ferruginous sandstone	7
White sandstone, Mentone, probably overlying the ferruginous sandstone	10, 11
Beach sand, largely derived from the coarse sand of the nodule bed	9

MECHANICAL COMPOSITION

The sandstones, being practically unconsolidated, were lightly crushed between the fingers, and were then quartered until an amount between 25 and 30 grams of sample remained. All subsequent examinations were made on these representative samples. For the mechanical analysis each sample (except the beach sand, no. 9) was wet sieved through a standard sieve with an aperture of 0.06 mm. The coarse material was dried and sieved by hand through sieves giving approximately the Wentworth scale of grades. The finest material was sedimented for the appropriate lengths of time to give grades of 0.06–0.03, 0.03–0.015, and finer than 0.015 mm diameter respectively. The results of the mechanical analysis are given in table 2.

The "sandiness" of these beds, as shown by the mechanical analyses, is given in table 3.

TABLE 2

Sample No.		1	2	3	4	5	6	7	8	9	10	11	ϕ Value
	Sieve opening, mm	%	%	%	%	%	%	%	%	%	%	%	
+	1.20	—	—	—	—	—	—	—	—	0.7	—	—	0
+	0.42	10.1	4.5	0.4	—	1.3	—	—	2.1	75.7	39.0	2.1	1.2
+	0.21	13.3	4.7	2.5	0.5	0.5	0.1	0.6	2.5	18.2	43.8	47.0	2.2
+	0.12	25.1	12.4	19.5	17.3	10.2	7.4	13.4	24.0	1.8	6.2	34.0	3
+	0.06	29.6	52.4	63.2	65.5	72.9	80.0	70.8	45.1	3.6	2.2	5.9	4
a	0.03	1.2	6.4	2.6	3.7	3.4	2.0	2.1	7.4	—	2.5	3.8	5
a	0.015	5.0	3.4	1.0	1.3	2.0	1.0	0.7	1.8	—	0.2	0.2	6
a	0.015	15.6	16.2	10.8	11.6	9.8	9.5	12.3	17.0	—	6.1	7.0	7

+ =retained on; a =obtained by sedimentation.

TABLE 3

Sample No.	Fine sand[1] %	Clay %	Section	Position in bed	Position in bed (after Singleton)
1	78	22	B	base	b
2	74	26	B	middle	b
3	86	14	B	top	b
4	83	17	B	base	c
5	85	15	B	middle	c
6	87	13	C	top	c
7	75	25	C	base	d
8	74	26	D	middle	b
10	91	9	—	base	?d
11	89	11	—	top	?d

[1] The fine sand is taken as the material greater than 0.06 mm diameter and the clay as that less than 0.06 mm diameter.

From these figures the average percentage of sand and clay in the various groups of beds is:

	Sand %	Clay %
Cheltenhamian fine brown sandstone	81	19
Mentone white sandstone	90	10
White sandstone, section C	75	25

The figures in tables 2 and 3 indicate that there is a slight variation in grain size between the base and the upper portions of the beds, but considerably more mechanical analyses are necessary from additional samples before these trends can be regarded as significant. The mechanical composition of the white sandstone (no. 7) from section C is very much more like that of the Cheltenhamian brown sandstone than it is the well-defined Mentone sandstone.

There are insufficient samples for a statistical treatment but the curves drawn from the mechanical analyses in table 2 do indicate the variation in the beds and the degree of sorting. The maximum grade in the Cheltenhamian beds is 0.12–0.06 mm diameter, whereas that of the Mentone sandstone is in the 0.4–0.2 mm diameter. The beach sand (no. 9) is very much coarser and must be largely derived from the nodule bed at the base of the Cheltenhamian.

The lower parts of the beds in the type sections contain a certain amount of lime which is sometimes visible as small white concretions. The lime content is gradually reduced through the thickness of bed b, so that in bed c very little is present and the sediment becomes a clayey sandstone rather than a sandy marl as in bed b.

MINERALOGY

The heavy minerals in the maximum grade material and in the next finer grade were obtained by separation in bromoform (sp. gr. 2.8). These are given in table 4. The minerals of the light fractions were examined in the 0.12–0.06, 0.06–0.03, and 0.03–0.015 mm grades with the exception of the beach sand (no. 9) in which coarser grades also were examined.

The figures for the heavy fractions indicate that the content is variable, but with the small number of samples examined no particular significance can be at-

TABLE 4. *Heavy minerals in the sedimentary rocks from Beaumaris*

	Ferruginous sandstone and marl, Cheltenhamian beds														White ss., Beaumaris		White ss., Mentone			Beach sand, Beaumaris	
Sample No.	1		2		3		4		5		6		8		7		10		11	9	
Grade	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	C	A
Heavy residue	% .2		% 1.7		% 1.3		% .7		% .4		% .9		% 1.0		% .2		% .5		% .8		% 1.7
Black opaque[1]	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Tourmaline	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Zircon	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+
Rutile	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+
Amphibole	+	+	+		+	+	+		+	+	+		+	+	+						
Chlorite	+																				
Epidote\																					
Zoisite }	+		+	+	+	+	+	+	+	+			+	+	+	+		+		+	
Garnet	+	+			+	+		+	+	+			+	+	+	+					+
Sphene		+	+	+			+								+		+				
Andalusite							+		+	+			+		+		+		+		+
Kyanite									+				+		+						
Staurolite			+				+						+		+				+		
Sillimanite															+				+		
Anatase		+		+											+				+		+
Brookite				+													+				
? Monazite										+				+					+		
? Zenotime		+															+				

[1] Magnetite and ilmenite. Grain-size: A =0.12–0.06 mm, B =0.06–0.03 mm, C =0.21–0.12 mm diameter.

tached to this variation. The beds themselves appear very similar, and any variations may largely be due to differences in the content of limonite or mixtures of limonite and other ferruginous minerals. There is a very significant difference, however, in the heavy mineral content of the basal white sandstone at Mentone (no. 10), which contains 5 per cent heavy residue.

The following minerals were recorded in the heavy fractions: magnetite, ilmenite, limonite (mostly coating other grains), zircon, tourmaline, rutile, amphibole, chlorite, epidote and zoisite, garnet, sphene, staurolite, andalusite, ?sillimanite, kyanite, anatase, brookite, ?monazite, ?xenotime. The distribution of these minerals is given in table 4 which shows that the minerals common to all these sediments are: magnetite, ilmenite, tourmaline, zircon, and rutile. The remaining minerals occur sporadically generally in very small amounts or as rare grains.

NOTES ON THE MINERALS

Opaque minerals.—Magnetite was removed with a magnet, the remaining black opaque grains being designated as ilmenite. There are also in these samples a considerable proportion of cream colored opaque grains which have the characteristics of leucoxene. No mention is intended here to limonite which occurs mainly coating other grains, although it is present in a much more massive form in the ironstone bands which are not described in this paper.

Tourmaline.—The residues yielded gray, blue, and brown grains of tourmaline which are generally not very well rounded, although spherical grains occurred in a few samples. Samples 1 and 7 contained parti-colored blue and brown grains. Blue tourmaline was much less plentiful than brown. Sample 7 contained the greatest quantity and variety of tourmaline, generally in somewhat worn prismatic grains, but larger fluted grains (gray) also occurred and apparently were confined to this particular sample. Bright blue and bright brown tourmaline were conspicuous in this sample.

Zircon.—Zircon is present in all the samples; it varies in habit from small, well-worn, prismatic grains to acicular grains exhibiting prism and pyramid faces with sharp edges. Rather squat, zoned grains were found in some samples, while in others "doublets," i.e. prismatic grains joined along the c axis and exhibiting individual pyramids at one end but joined into a single pyramid at the other, occurred. Other habits noted were: grains consisting of a combination of and intergrowth of several prisms and pyramids; acicular, with a number of ditetragonal prisms. Inclusions are common in some types. Most of the zircon is colorless, but in sample 7 a few brownish zircons with inclusions occurred, and zoned zircons are characteristic of sample 8. The examination of additional material from the same stratigraphic horizons probably would indicate that the various types of zircon could be used for index purposes.

Rutile.—Three varieties of rutile, which is not abundant in these sediments, were noted; yellowish brown worn prismatic grains, reddish brown grains, and worn geniculate twins. As the latter were seen only in the beach sand (no. 9), it is possible that this form is not present in the ferruginous marls. In sample 10 the rutile has the appearance of being authigenic.

Amphibole.—Small quantities of amphibole were recorded from a number of the samples. The amphibole is generally in small somewhat ragged worn grains, bluish to yellowish green in color. In samples the amphibole had $Z \wedge c = 15°$ but bright blue-green, slightly pleochoric, grains with $Z \wedge c = 21°$ occurred in sample 3. The amount of amphibole varies in different parts of the ferruginous sandstone, being most plentiful in sample 5; it is scarce in the white sandstone (no. 7) above the ferruginous beds, in the beach sand (no. 9), and apparently is absent from the sandstone at Mentone (nos. 10, 11).

Chlorite.—A few grains having the ap-

pearance of amphibole but without its optical properties have been referred to chlorite.

Epidote and zoisite.—Very pale yellow green to colorless grains, sometimes composite, and of an irregular "carious" worn appearance have been identified as belonging to the epidote-zoisite group. Such grains are commonly present in all of the samples with the exception of no. 6. The optical properties of this mineral leave no doubt as to its identity. It is interesting that no true epidote was found.

Garnet.—Very small quantities of three varieties of garnet were found in these sediments; colorless, pale pink, and brown. Of these, the colorless variety in angular small grains is the most frequent. A few isotropic brown grains have been identified as brown garnet rather than spinel, as the color is not very deep and the grains could not be removed for a more complete identification. Baker (1945) has made some interesting observations concerning the source of the brown garnet.

Sphene.—Sphene in colorless grains with the usual optical properties is a minor constituent, and appears to have a sporadic distribution in these sediments.

Andalusite, kyanite, staurolite, sillimanite.—This group of metamorphic minerals is present in small quantity in a number of the samples (see table 4). Andalusite, with some grains strongly pleochroic, is the most plentiful of these; staurolite in angular grains occurs in a number of the samples; kyanite is present as worn, typical grains in the upper parts of the ferruginous sandstones, and in the white sandstone above it (no. 7). A number of colorless fibrous grains, some with strong polarisation colors, but others giving anomalous optical properties, were identified as sillimanite. The grains with anomalous properties represent micacised sillimanite grains. They were recorded only from nos. 7 and 11.

Anatase, brookite.—These authigenic titanium minerals occur in small quantities in a number of the sediments, anatase being much more plentiful than brookite. Anatase occurs in steel-gray to pale yellow square tablets in samples 1, 2, 7, and 11, but in the beach sand (no. 9) it is in steel-blue octahedra. Brookite is in yellow irregular fragments with typical optical properties. These two minerals have formed as a result of the alteration and break-down of ilmenite which has released titanium and iron, the latter adding to the color of the beds and to the nontronite component of the clay material.

Monazite, xenotime.—Monazite occurs in slightly rounded pale green grains. Xenotime is tentatively identified as certain yellowish green grains with the habit of zircon. Both minerals are recorded only as rare grains in several of the sediments.

The light fractions.—The minerals present in this fraction are: quartz, feldspar, clay minerals (mostly nontronite), micaceous grains, and organic remains. The grains were somewhat obscured with adherent ferruginous and clayey material which was removed by boiling in 1:1 conc. HCl. Three grades of each sample were examined, 0.21–0.12, 0.12–0.06, and 0.06–0.03 mm diameter.

Quartz.—The grains were angular to subangular in shape, and there were few grains which showed a greater degree of rounding than this. In the white sandstone from Mentone (nos. 10, 11) there was a greater proportion of well-rounded grains. Almost invariably the finest grade examined contained angular chips of quartz. It is noticeable that the larger grains of the coarser grades showed a greater degree of rounding, a feature which appears common to most sands and sandy sediments. The quartz contains few inclusions, pepper-dust magnetite or ilmenite being the most common.

Feldspar.—Feldspar forms only a small proportion of the light fraction, but after cleaning the following were recognized: microcline, orthoclase, microperthite, and an acid plagioclase. Of these, microcline is the most prominent, the greatest quantity being in no. 6; nos. 10, 11 are practically devoid of it.

Micaceous grains.—Flakes of mica were

seen during the preparation of a number of the samples, but microscopic examination failed to reveal any characteristic mica. This platy mineral, which had lost its original brown color on acid treatment, is therefore probably a clay mineral, but may originally have been a true mica.

Nontronite.—The approximate clay content of these sediments is given in table 3. The principal clay mineral, which has been identified as nontronite, occurs as irregular, gel-like masses, as grains consisting of innumerable small superimposed plates, or as coating other minerals, e.g. quartz. It is also present as internal fillings of foraminifera. It is brownish yellow to brownish green in color, and isotropic to birefringent with second order colors; occasional grains are seen to be made up of bundles of fibres; it is often slightly pleochroic. Grains with dense centers often have a weakly birefringent border showing radial polarization. It has been stated that these beds contain glauconite (Singleton, 1941, p. 78), but the optical properties indicate that the brownish mineral is one of the nontronite group. It is possible that some of the opaque brownish grains may be glauconite somewhat altered and obscured by a coating of limonite, into which mineral it is likely to alter fairly readily if the conditions are suitable. The clay mineral is also present in the white sandstone (no. 7) overlying the ferruginous beds, and in the Mentone sandstone (nos. 10, 11), where it is pale in color and differs in habit and optical properties from that in the Cheltenhamian beds. In these samples it is at least equal to quartz in quantity (in the grades examined microscopically); it is in clear gel-like grains with micaceous habit (but not formed by superimposed overlapping plates), moderate birefringence, and undulose extinction. It does not coat quartz grains to any appreciable extent. The differences may largely be due to the low iron content of these sediments.

Organic remains.—Remains of shell fragments and foraminifera are present in the lower parts of the Cheltenhamian beds, but do not make up any appreciable part of the sediments themselves.

DISCUSSION

Both the mechanical composition and mineralogy of the Cheltenhamian beds at Beaumaris indicate that the source of the material was in pre-existing sedimentary rocks. The Tertiary marine transgression which occurred in this part of Australia probably reached its final stage (Singleton, 1941, p. 60) by upper Miocene (Cheltenhamian) times. There is a slight break in sedimentation at the base of the Cheltenhamian, the nodule bed, and some slight variation due to the development of coarser layers in the more thinly bedded sandstones overlying the type Cheltenhamian which is a thick bed of uniform character. The lithological character of the overlying ferruginous sandstones, with the exception of the bands of ironstone, is very similar to the Cheltenhamian throughout their thickness. At the base of the Cheltenhamian beds lime and small lime concretions occur, the sediment being a marl, whereas the upper parts are ferruginous clayey sandstones. The mechanical analyses indicate that sample 1 is less well-sorted and somewhat coarser than nos. 2 and 3 from the upper part of the bed, and that nos. 4 and 5 are very similar to nos. 2 and 3.

There is no well-marked difference in mineralogy. That all the ferruginous sandstones in this part of Port Phillip Bay are similar mineralogically is suggested by Baker's (1945) records of heavy minerals in beach sands, the origin of the constituent minerals being suggested from his knowledge of the Mesozoic and Palaeozoic rocks of Victoria. Both lithologically and mineralogically there is a break in sedimentation between the Cheltenhamian beds and the presumably overlying white sandstone at Mentone, but there is no break between the ferruginous sandstones and the white sandstone at Beaumaris (section C).

The results of this investigation indi-

cate that the beds in the section at Beaumaris, including Singleton's Cheltenhamian stage, are one stratigraphic formation. Singleton (1941, p. 78) has suggested that the unfossiliferous beds above his type section may be Kalimnan (lower Pliocene), a view also held by Crespin (1943, p. 64). The mineralogical and mechanical composition of these beds clearly show that there is no lithological break in sedimentation, but further critical examination of the fauna, particularly the foraminifera, is required for satisfactory age determination. The white sandstone at Mentone is post-"Cheltenhamian."

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FIG. 1, DECEMBER, 1949

LOESS, AN EOLIAN PRODUCT

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ABSTRACT

Petrographic characteristics and field relationships of Dutch and of Mississippi Valley, United States, loess deposits are described. The evidence indicates that the loess of both regions is eolian in origin.

Whether loess is an eolian product or a water-laid deposit still seems to be an unsettled problem. Although the eolian genesis probably is more widely accepted, other explanations for its origin continuously appear.

R. J. Russell (1944) refers to van Rummelen who defended the non-eolian theory of the Dutch loess in many papers. In the meantime, however, the eolian origin of the Dutch loess has been proved by van Doormaal (1945).

In 1927 Druif pointed out that the mineralogical composition of the Dutch loess was different from that of the underlying formations. Edelman confirmed this on a quantitative base. Van Doormaal continued these studies on a larger scale. He gives extensive petrological descriptions of many sections of the loess of the southern part of the province of Limburg in the Netherlands. These profiles are very similar to those of the Mississippi River Valley. The author will give two of them for comparison with those of R. J. Russell. (See "Profiles of Dutch loess.")

All features given by Russell are found also in the Dutch loess. In some layers gravel occurs and creep (solifluction) can be observed especially well in the older loess (zone IV). The deposit is evenly distributed over nearly the entire area. In the valleys the thickness is increased, in some places, due to solifluction.

Two high points, however, are not covered with loess and these are always used as proof against the eolian origin. Both localities, however, have definitely eroded surfaces. Van Doormaal showed that there exists a transition between the loess-covered and loess-free areas. The wind-blown sands which cover the loess-free spots get more and more mixed with loess material toward the typical loess-covered parts.

The loess overlies Cretaceous limestones, Oligocene and Miocene sandstones, and Pleistocene river terrace deposits.

The mechanical composition is given in figure 1. It is very homogeneous. The grade 50–10μ makes up 60–80 per cent of the deposit. The grades $>50\mu$ are less than 5 per cent and those $<10\mu$ less than 30 per cent. The size frequency distribution is similar to that of the Mississippi River Valley loess.

According to unpublished data of Dewez, a gradual change in the mechanical composition exists between the loess and fine, slightly loamy sands toward the north. These sands form a nearly continuous, thin cover over a large part of the Netherlands and are supposed to be wind-blown.

The heavy mineral composition of the loess is entirely different from that of the underlying formations and the recent deposits of the Meuse River. Table 1 gives a selection out of more than 300 samples investigated for heavy minerals by Druif, van Baren, Edelman, Van Doormaal, Muller, and Zonneveld.

The theory of van Rummelen that the Dutch loess is a weathering product of

Profiles of Dutch loess

Quarry, Brick factory at Beek

Zone I 0–20 cm.
Gray loam, free of lime.
Zone II
(a) 20–150 cm.
Light brown to reddish or chocolate brown loess, free of lime, many large root tubes, reddish brown spots of $Fe(OH)_3$ and black spots of Fe- and Mn-concretions. A few small yellow silt lenses. Bottom layer lighter brown.
(b) 150–240 cm.
Light brown loess with many horizontal, yellow lenses up to 2 cm thick and maximum 200 cm long. The lenses follow shape of pockets in zone III. Many small root tubes. Structure gets looser downward. Non-calcareous.
(c) 240–270 cm.
Light brown loess without lenses, small root tubes. Color gets more yellow. Loose structure. Free of lime.
Zone III 280–665 cm.
So called "Eerdmergel" (earthy marl), calcareous. Top well marked, undulating. From 280–470 cm, an even straw yellow color, with root tubes. Between 330 and 470 cm many small veins of $CaCO_3$. From 470–665 cm horizontal lamination of more or less compact layers. In bottom layers brown spots of $Fe(OH)_3$ due to action of ground water.
Zone IV 665–695 cm.
Calcareous, compact, greenish yellow loam. Solifluction phenomena.
Zone V below 695 cm.
Terrace gravel.

Graetheide, Welzenheuvel, old lignite quarry

Zone I 0–25 cm.
Grayish yellow loam, top layer a black forest soil mixed with lignite dust and Miocene sand, white sand grains (podsol). Lower layer sandy loam, with pieces of brick. Loose structure.
Zone II 25–325 cm.
Non-calcareous loess, leached.
(a) 25–145 cm.
Yellowish white to yellowish brown loam getting more compact to 75 cm and looser further downward. Varying colors with white spots down to 90 cm. Below 90 cm even yellow color with light yellow, sandy spots.
(b) 145–275 cm.
Alternating yellowish white and brownish yellow, horizontal layers of varying thickness. Their lengths may be many meters. The thickness decreases downward.
(c) 275–325 cm.
Non-laminated loam, yellow with orange yellow spots. Transition to zone III is sharp, undulating.
Zone III 325–450 cm.
Calcareous loam, slightly lighter than overlying zone and locally with orange yellow spots. Lime concretions. Between 425 and 450 cm folded due to solifluction. Concretions on surface of laminae.
Zone IV 450–575 cm.
Heavy, slightly plastic loam, orange to brownish red, non-laminated, slightly calcareous. 450–525 cm even color with blackish brown spots. 525–575 cm slightly laminated, brownish red to whitish yellow. Some pieces of flint. Probably a "gley" horizon.
Zone V Below 575 cm.
Terrace sand and gravel.

the Cretaceous should involve an increase of the number of mineral species with epidote and hornblende during the weathering. The Tertiary formations do not contain these minerals either.

Zonneveld informed the author that 8 river terraces can be distinguished by means of heavy minerals. He examined more than 100 samples. They contain less than 1 per cent epidote and garnet. A brown hornblende variety which sometimes is present, does not occur in the loess. The terrace deposits contain a high percentage of zircon, tourmaline, staurolite, kyanite and sometimes chloritoid.

The mineralogical similarity between the loess and the glacial deposits in the north is striking. The loess components, however, could have been derived from these glacial formations only if they had been transported by the wind.

The investigation of van Doormaal proves the eolian origin of the loess in the Netherlands. His work furthermore shows that loess studies should be made with mechanical analyses and mineralogical investigations of many samples of

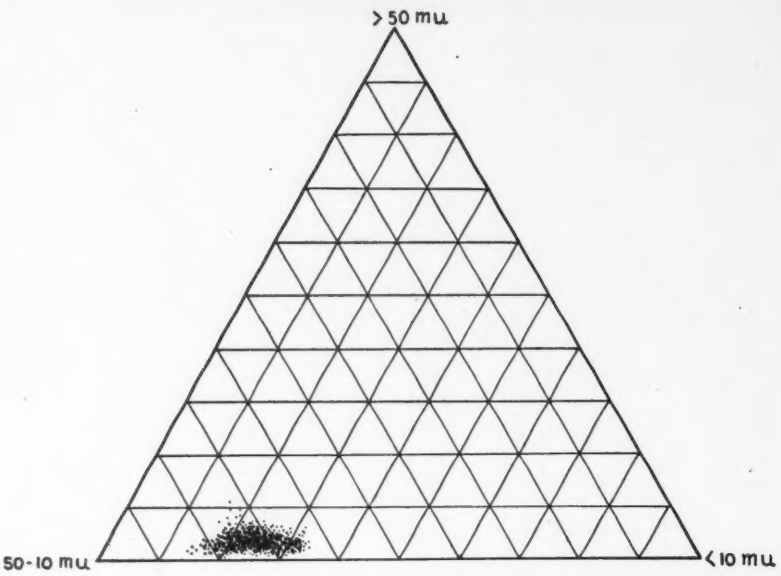

FIG. 1.—Mechanical composition of Dutch loess samples.

the deposit itself and the underlying formations, combined with a study of the regional distribution of the deposit.

In 1946 the author was able to collect a few samples of the loess and underlying formations during an excursion with Prof. R. J. Russell along the Mississippi River Valley between Doloroso and Vicksburg, Mississippi.

Table 2 gives the heavy mineral data of these samples. The microscopic determinations were made by Miss S. M. van der Baan. Heavy mineral data of recent sediments of the Mississippi River shown in table 2 are taken from the study of Dana Russell. The percentage of the heavy non-opaque minerals have been calculated from his paper.[1]

For the Mississippi River Valley the difference in mineralogical composition between the loess and the underlying river terrace sands and upper Tertiary formation is also evident. The upper Tertiary and the terrace sands contain staurolite-kyanite-zircon assemblages, the loess has a garnet-epidote-hornblende association. Epidote, garnet and hornblende are absent in the older formations. Only the uppermost terrace sand on highway 61, one mile south of Doloroso, contains 4 per cent of epidote and a few grains of hornblende. This may be due to admixture of loess material during its deposition or to contamination with loess at the surface of the exposure.

The loess samples 13 and 15 contain a lower hornblende, epidote and garnet content; 13, furthermore, contains a higher percentage of staurolite, kyanite and zircon. These samples also contain gravel and show creep phenomena. During the solifluction terrace material moved also and mixed with the loess. This caused a lowering of the percentage

[1] Dutch sedimentary petrologists always give the mutual percentage of the non-opaque minerals and, in addition, the opaque minerals as percentage of the total heavy fraction.

TABLE 1.—*Minerals of loess and other sediments from the Netherlands*

Sediment type and locality	Opaque	Tourmaline	Zircon	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Hornblende	Glaucophane	Augite	Hypersthene	Enstatite	Saussurite	Picotite	Diaspore
Loess, Quarry Beek																						
Zone I, 0–20 cm	45	2	31	13	13	2	2		3	3	1			25	5							
Zone II, 20–45 cm	34	1	29	21	11		1	1	2	2				28	4							
Zone II, 155 cm	40	5	21	16	11		2	2	3	2	1			32	5							
Zone II, 210 cm	41	1	29	7	16	3	3		3	5				25	7	1						
Zone III, 320 cm	43	1	26	29	15	1	2	1	1	2	1			18	2							
Zone III, 430 cm	40	1	24	11	19		3			8				29	5							
Zone III, 650 cm	36	1	20	19	14	1	4	3	1	4	1			24	6					2		
Zone IV, 685 cm	49	3	35	16	6		2	2	3	4	1	1	1	19	7							
Loess, Greatheide																						
Zone I, 4–25 cm	36	2	39	10	15	1	5		2	1	2			21	2							
Zone II, 145 cm	43	1	30	17	10		6		1	55				24	5							
Zone II, 300 cm	46	2	31	25	10	1	4		1	3				18	7							
Zone III, 440 cm	50	1	34	11	19	2	8		3	2	1			19								
Zone IV, 535 cm	45	1	32	3	14	4	9	3	4	4	1			25								
Mixed Loess, Heerlen																						
Zone III	67	8	48	3	17	3	4	1	5	3	1			4	1					2		
Cretaceous	59	7	66	1	20	2	2	1		1												
Oligocene	57	14	38	3	25		6	1	6	5	2											
Miocene	47	11	40	3	18	1	4		9	10	3					1						
Pliocene	52	20	33		26		1		5	8	5			2								
Pleistocene Terrace	43	18	48	2	20	1	1			3	3	1		3								
Recent Maas River sand (16 samples)	45	16	10	22	3				7	2	2		27	2	2		4			3		
Average Glacial deposits N. Netherlands	30	2	12	18	8			1	2	2	1			40	13					1		

of the characteristic loess minerals and an increase of those of the terrace material. This also has been observed by van Doormaal in the Dutch loess. The mechanical analyses of such samples generally give a higher content of grades $>50\mu$ and a too high or too low percentage of the grade $<10\mu$.

The few samples of the Mississippi Valley loess which have been investigated indicate that they can not have been derived from the terrace deposits or Tertiary formations. The loess does not contain pyroxenes which are present in about the same percentage as hornblende in the Recent Mississippi River sands (Dana Russell).

A more regional study of the Mississippi River Valley loess, combined with mechanical and mineralogical analyses of many samples has to be made in order to ascertain the dissimilarity of the loess and the underlying formations and to make sure that its composition is uniform over a large area.

The theory of the non-eolian origin of the loess and its derivation from backswamp deposits, pushed forward by R. J. Russell, has not been confirmed by mineralogical evidence. It seems rather certain that the Mississippi loess is of eolian origin just as well as the Dutch loess.

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TABLE 2.—*Minerals of loess and other sediments from the Mississippi River Valley, U.S.A.*

Sediment type and locality	Opaque	Tourmaline	Zircon	Garnet	Rutile	Brookite	Anatase	Titanite	Staurolite	Kyanite	Andalusite	Sillimanite	Chloritoid	Epidote	Hornblende	Glaucophane	Augite	Hypersthene	Enstatite	Saussurite	Picotite	Diaspore
Loess (weathered), Highway 61, 12 miles S. of Vicksburg, Miss.	35		20	23			12	1						18	25						1	
Loess, North of Highway 61, 12 miles S. of Vicksburg, Miss.	61	2	25	12			6			1				25	29							
Loess, South of Highway 61, 12 miles S. of Vicksburg, Miss.	33		18	16	4		8	1	2	1				19	30						1	
Loess, Highway 61, 4 miles S. of Natchez, Miss., 3′ above low. layer	51		19	18	1		5			3				24	30							
Loess, Highway 61, 4 miles S. of Natchez, Miss., 3′ above low. layer	18		16	14			1	2		1				29	39							
Loess, Highway 61, 4 miles S. of Natchez, Miss., lower layer	34	1	10	20	2		5	1	2	2				10	47							
Loess, Highway 61, 4 miles S. of Natchez, Miss., lower layer, mixed	59	2	30	5	9		8		10	15				16	5							
Loess, Highway 61, 4 miles S. of Natchez, Miss., low. layer (with gravel)	49	3	31	12	6		9	1	1	3				17	17							
Loess, Highway 61, one mile South of Dolorosa, Miss.	32		18	14	3		3							19	42						1	
Terrace sand, Highway 61, one mile South of Dolorosa, Miss.	67	4	50	1	3		10		6	26												
Terrace sand, Highway 61, one mile South of Dolorosa, Miss.	58	6	48	1	5		3		11	18		3		4	1							
Williana Terrace sand, half mile S. of Dolorosa, Miss.	60	5	34		7		1		16	33		4										
Williana Terrace sand, 2 miles North of Washington, Highway 85	78	6	38	1	5		8	2	16	18	2	4										
Upper Tertiary, Highway 61, one mile South of Dolorosa, Miss.	39	6	62	1	8		11		6	6												
Upper Tertiary, Highway 61, one mile North of Dolorosa, Miss.	42	10	57		13		11		6	3												
Mississippi River sand near Vicksburg, Miss., Recent		*	11	22	*			6	*			*		22	25		14	*				
Mississippi River sand near Natchez, Miss., Recent		*	2	21	*			2	*	*		*		22	33		18	2				
Mississippi River sand near Natchez, Miss., Recent		*	4	14	*			4	*	*				19	37		21	1			*	

* Mineral present below 1 percent.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 19, NO. 3, PP. 118–127
FIGS. 1–9, DECEMBER, 1949

CLAY DUNE FORMATION NEAR CORPUS CHRISTI, TEXAS

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Norman, Oklahoma and Corpus Christi, Texas

ABSTRACT

Desiccation of saline mud flats produces a mud-cracked surface layer of clay impregnated with saline evaporite crystals and covered with a thin film of algae. The action of the wind against the upturned edges and lower surfaces of the mud-cracked polygons frees pellets or aggregates of clay which are swept across the tidal flat or saline basin to accumulate along the lee shore in long, transverse ridges. Subsequent wetting causes the clay to regain its plasticity, the freshly deposited material becomes stabilized and the clay dune results.

INTRODUCTION

Elongate ridges of compacted and stratified wind-blown clay form conspicuous topographic features along the north and west sides of the Oso Creek estuary, near Corpus Christi, Texas. These vary in height from a few feet to nearly thirty feet and can be traced continuously for several miles along the lee side of the tidal flat. Deposition of fresh material is currently taking place in the frontal slope and the dunes are actively prograding toward the source.

The field work which serves as a basis for this report was done during the spring, summer, and fall months of 1945 and 1946.

HISTORY OF PREVIOUS INVESTIGATIONS

Clay dunes have been mentioned briefly in the literature but detailed studies of their development have not been undertaken. They were first identified in the South Texas region by Coffey (1909) who observed granules of clay being transported across saline flats of intermittent lakes and coastal lagoons along the lower Texas Gulf Coast and accumulating against ridges or dunes of clay. The dune material was mapped and described as the "Point Isabel Clay" (Coffey, 1912). Subsequent studies and mapping of the "Point Isabel Clay" were made by various soils men (Beck and Henderson, 1928, Hawker and Simmons, 1929).

The first detailed discussion of the nature and distribution of clay dunes in the South Texas area was by Price (1933) who mentioned the occurrence of clay dunes along the Oso Creek estuary near Corpus Christi, Texas.

Clay hills bordering saline basins in central New Mexico were identified by D. W. Johnson (1902) who indicated their eolian nature by calling them "dunes of white adobe soil." The eolian origin of the saline basins associated with the clay hills was recognized by Keyes (1908), who described "shallow lake basins hollowed out of the plains-floor by the wind."

Extensive development of clay hills associated with the salt basins of Estancia Valley, New Mexico, was reported by Meinzer (1911) who described them as "hills and ridges composed of pale, yellowish gray, fine-grained pulverulent dust of clay containing no pebbles or grit."

Similar features, probably genetically related, have been termed "lunettes" in southeastern Australia where they form crescentic mounds on the lee side of lakes (Cotton, 1942, Stephens and Crocker, 1946).

Drifts and low dunes of sand, clay pellets, or salt crystals, depending upon the material available, have been recognized by Blackwelder (1946) on the lee side of barren plains or playa lake beds in arid regions.

Low transverse dunes of clay termed

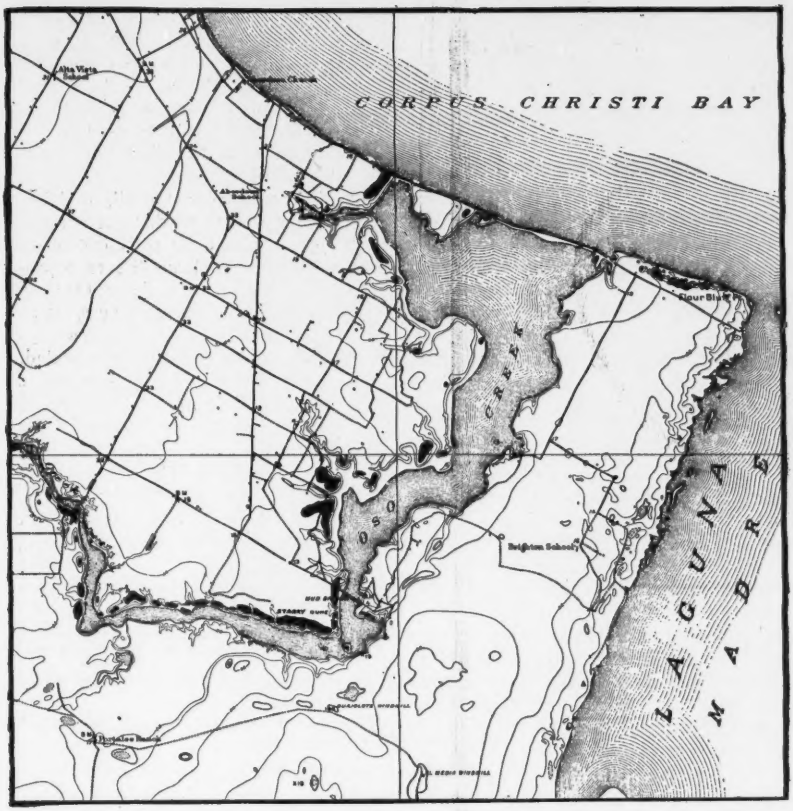

FIG. 1.—Map showing location of clay dunes along Oso Creek, Nueces County, Texas.

"axle-busters" or "desert ripples" have been described by Ives (1946). These are on arid flats of Pleistocene lakes and other depressions as in the southern part of the Bonneville flats of Utah, the Lechugilla Desert of Arizona, and in the Altar Desert of Sonora in northwestern Mexico. Lesser amounts of sand accumulate against the lee sides of the ripples.

DISTRIBUTION OF CLAY DUNE LOCALITIES

Regional.—Coastal plains of Quaternary and Recent age are favorable localities for clay dune formation. Well developed clay dunes exist along the South Texas Gulf Coast from the mouth of the Rio Grande River to Corpus Christi, Texas, where their distribution is controlled by climatic factors. They are

known to occur southward along the coast of Tamaulipas, Mexico.

In desert areas, clay dunes occur on clay-floored playas, either as a field of stabilized transverse dunes (desert ripples) or as lee shore dunes of considerable height. They have been reported from several areas in the arid southwestern portion of the United States and it seems probable that they are distributed rather widely throughout that region.

Local.—Local occurrences include the lee sides of saline mud flats of inner waters, shallow estuaries, lagoons, and intermittent saline lakes or playas, either as shore dunes or in fields of desert ripples.

CLIMATIC CONDITIONS IN THE CLAY DUNE ENVIRONMENT

Clay dunes form on the lee sides of saline lake basins and coastal lagoons in arid, semi-arid, and dry sub-humid climatic zones where evaporation exceeds precipitation. A strong or moderately strong wind blowing rather consistently from one direction during the dry months of the year is requisite for their formation.

Dunes grow only during the drier months of the year when the soil is not continuously wet, frozen, or covered with snow. In the south Texas area, movement of the clay pellets begins in the month of March and continues until November when the growth of dunes is arrested by winter precipitation and reduced evaporation. Their growth is most rapid during the drier summer months and during periods of prolonged drought. Winter activity consists primarily of the reworking of previous deposits by both wind and rain.

GENERAL CHARACTERISTICS OF CLAY DUNES NEAR CORPUS CHRISTI

Clay dunes are developed typically along the north, northwest, and west sides of Oso Creek, Corpus Christi Bay, Nueces County, Texas, where they form prominent ridges ranging from 2 feet to nearly 30 feet in height (see figure 1). They extend more or less continuously for several miles, broken only by deep transverse gullies. Widths vary from 800 to over 1500 feet. On the lee slope, they merge gently with the underlying Beaumont surface; where little eroded, the gentler slope faces the direction of the prevailing wind.

The dune ridges are typically multiple with as many as three distinct summit levels representing three periods of dune growth. Older dune elements form a pronounced ridge whose complex nature can be determined only in fresh cuts, as at the Mud Bridge locality, where two cycles of older dune growth are revealed. The younger of the dune summits is active today and forms a low ridge of freshly deposited clay in advance of the older dune.

A representative profile section made across the Starry Farm dune, figure 2, indicates a relatively symmetrical form of the older, stabilized dune. The surface is smooth except where gullied by run-off and rills. The slopes on the flanks have a ratio of approximately 1:25, being slightly steeper on the leeward side. The older dune is being eroded actively and the younger dune is receiving annual additions of fresh clay.

The stabilized clay dune is composed of yellowish-brown clay characterized by a banding of darker layers which accumulated during periods when excessive organic matter was derived from the flat. The fresh clay dune material is soft and fluffy and usually very dark in color. Upon wetting, a thin crust forms which prevents further movement of the clay granules. Weathering and erosion of the older dune face and the frequent reworking of the material by run-off forms a zone of mixed eolian and fluvial material along the landward margin of the younger dune. Deposition of these materials in the gullies which traverse the dune forms complexly laminated deposits of small scale. A prominent 6-inch bed of fine sand occurs locally in the upper part of the second summit level.

The slopes of the stabilized clay dune

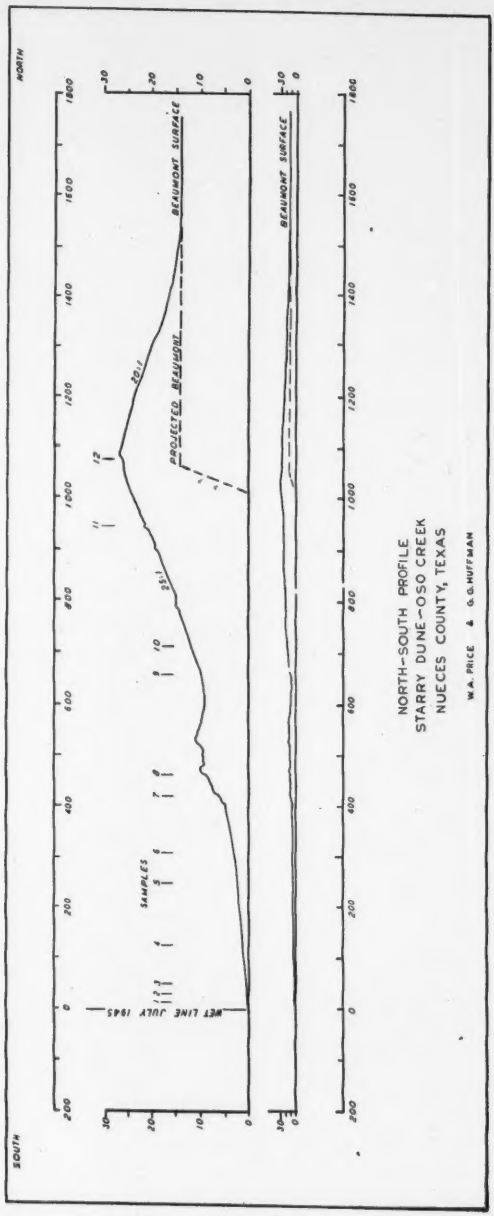

FIG. 2.—Profile section across Starry Farm dune, Oso Creek, Nueces County, Texas.

are covered with a sparse blanket of grasses, cactus, mesquite, and other typical South Texas plants. The fresh dune surface is essentially barren of vegetation. Ungrazed dunes may be heavily grassed, with less active dune growth; eroding dune flanks cause local prograding and more active return of eolian deposits.

ORIGIN AND FORMATION OF CLAY DUNE

Source of material.—Clay dunes form in the lee of large tidal flats and saline basins where broad mud bottoms are exposed to periodic wetting and drying (figure 3). Withdrawal of the water is followed by the formation of a thin film of algae (pond scum) over the surface of the flat. Upon drying, a thin crust or layer ($\frac{1}{4}$ to $\frac{1}{16}$ inch in thickness) of colloidal clay and silt impregnated with crystals of salt forms. Desiccation of this crust results in the formation of extensive mudcracks and polygons (figure 4) whose upturned edges are exposed to the strong south and southwesterly winds during the summer months. The impact of the wind against these upturned edges and the exposed undersurfaces causes granulation of the mudcracked layer; the resultant particles are sufficiently bound together by the saline salts, algal fibers, and retained moisture to behave as individual granules or pellets which are moved across the tidal flat by the wind.

Methods of movement.—Movement of the clay pellets is largely by surface creep and saltation. Some fine material is carried in suspension as attested by the deposition of a film of dust beyond the margin of the average material in transit. Quantitative measurements of the relative amounts carried by each of these methods, comparable to those of Bagnold (1941) and Chepil (1945, 1946), have not been made; field observations indicate that most of the movement is within a few inches of the ground.

The behavior of the particles in transit across the tidal flat is modified by the nature of the surface over which they pass. Clay pellets, moving over a roughened surface characterized by mudcracks and algal flakes or across an area previously deflated, tend to advance in a series of nearly parallel ripples or windrows as shown in figure 5, which migrate as the eddy currents sweep the particles from one ridge to another. Cessation of the wind may leave these parallel ripples of loose material temporarily inactive on the tidal flat. Across stretches of unbroken crust, which have not yet reached the critical stage of dryness necessary for the formation of mudcracks, the clay granules are swept along in an almost continuous sheet.

Deposition of the clay pellets.—Deposition of the clay granules occurs wherever obstructions cause a slackening of the wind. Locally, temporary deposits in the form of long, low transverse ridges or windrows are made as the particles advance across the tidal flat. Increased velocity or renewed activity of the wind, sometimes accompanied by further desiccation of the tidal flat, brings these deposits into transit once more. The second temporary lodgment of the clay particles occurs along the trash lines which mark the furthest advance of the previous tide or the high water mark. Here bits of stick, weeds, insects, and other debris left at the strand line afford sufficient obstruction to cause accumulation; these deposits persist only until the next wetting of the tidal flat (figure 6).

The first permanent clay dune deposit occurs just beyond the highest tide line where small clumps of vegetation give rise to small shrub-coppice mounds. Continued deposition of material in the lee of these obstructions forms elongate elements parallel to the direction of the wind. These fingers of fresh dune material extend across the surface of the growing dune where their maximum extent is clearly defined by the contrast in color and texture of the black, fluffy, fresh material lying on the paler, grayish, surface crust of the previous year (figure 7). The surface of these longitudinal elements is marked by the development of extensive ripple marks as shown in fig-

FIG. 3.—Broad expanse of the Oso Creek tidal flat near Corpus Christi, Texas. Note clay dunes to the left.

FIG. 4.—Details of the mud-cracked surface of the tidal flat following drying.

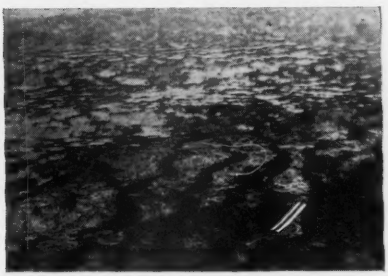

FIG. 5.—Windrows of clay granules in transit across the roughened surface of the tidal flat.

FIG. 6.—Temporary accumulation of clay pellets along the trash line formed by advance of preceding high tide.

FIG. 7.—Fresh dune material lying on lighter colored crust of the previous year's accumulation.

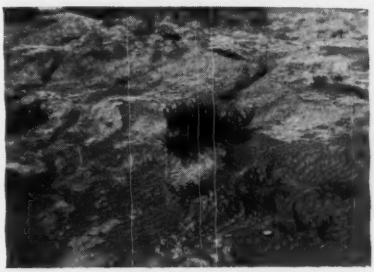

FIG. 8.—Ripple-marked surface of fresh clay dune deposits.

ure 8. These elongate dune fingers coalesce laterally to form a greater, transverse, source-bordering lee dune situated normal to the direction of the prevailing wind and essentially parallel to the edge of the tidal flat. The farthest advance of the earliest dune was controlled by the original bank of the stream whose bed now forms the tidal flat.

Stabilization.—The clay dune is stabilized by restored plasticity of the clay which takes place as soon as sufficient moisture is absorbed by the incorporated evaporite salts or the clay is wetted by rain. Thereafter, the clay takes on most of the properties of a normal clay and its position and form become stabilized.

Wasting.—The older summit levels of the heavily grazed clay dune ridges are being actively eroded and prominent gullies scar both the front and lee slopes. Erosion and weathering are more intense on the windward side and in some places have progressed sufficiently to produce miniature badland topography. The lee slope is typically less intensively eroded and gently merges with the slope of the Beaumont surface.

Rate of growth.—Measurements indicate that at one locality the 1945 and 1946 accumulations advanced inland approximately 700 feet from the shoreward edge of the dune and that clay granules moved as much as 940 feet from the low water line. Quantitative methods for measurement of volume of dune growth have not been successfully applied due to the extremely irregular nature and form of clay deposition. Fresh material accumulates rapidly on the low, uncompacted dune in the foreground and one to several inches of soft, fluffy material may accumulate in irregular patches during one season. However, upon wetting and compaction, this reduces to a thin layer.

Archeological studies provide the most reliable tool for dating the clay dunes in the Corpus Christi area. Bits of pottery, flints, bird points, Buffalo points, and other artifacts have been found within the dune layers. The summits of the older dune yield abundant shells of oysters, snails, and other forms left there by early Indian tribes who camped along the shores of Oso Creek. These relics have been examined by Sellards (1930) who regards them as ancient but not "prehistoric" and who concludes that the slow building of the dunes must have required several centuries. Detailed archeological investigations, now being undertaken, are expected to yield information which will result in more precise dating.

SIZE AND SHAPE ANALYSIS OF THE CLAY DUNE MATERIAL

Procedure.—Twelve representative samples of the clay material were collected across the surface of the dune; their positions were projected onto the profile section of figure 2. The samples were collected carefully, numbered consecutively, photographed, and examined under the binocular microscope. Samples 1 through 3 were collected on the tidal flat in front of the clay dune and contain alluvium, algae, sticks, and other foreign material. Samples 4 through 9 were collected from the freshly deposited dune surface and represent the material in transit across the active summit of the Starry Farm dune. Samples 10 through 12 were taken beyond the margin of the fresh dune material on the lower slope of the older dune and are a mixture of the fines carried over the active dune and silt and sand eroded and washed from the frontal slope of the eroding dune in the background.

Samples 4 through 9 are considered representative of the material in transit across the dune and have been examined carefully. Samples of approximately thirty (30) grams of fresh material collected from each locality were gently and evenly poured through a set of Tyler screens. After 3 minutes of gentle handshaking in both a rotary and an up and down movement simulating that of a ro-tap machine, the fractions were weighed and size-grade distribution determined. The accuracy of such a method is questionable, but a recheck screening

of one of the samples indicated a negligible amount of abrasion during the operation. The results of the size-grade analysis are listed in table 1 and are shown graphically on a cumulative-frequency curve in figure 9. After the screening, various fractions thus obtained were examined under the microscope for shape determinations and method of aggregation.

The size-grade determinations of table 1 indicate a progressive and marked decrease in size of particles from windward to leeward across the dune. The cumulative-frequency curves, figure 9, show a marked shifting of the median from 0.33 mm at 250 from the wet line to 0.16 mm at 800 feet. This progressive decrease in size of particles across the dune is clearly a combination of effects; the most obvious and important in the steady diminution is the breakdown of the quartz aggregates in transit. The clay particles likewise undergo abrasion and frequently show cracks and lines of breakage. A third factor is the selectivity of the wind which tends to leave the coarser particles near the front of the dune and to keep the finer particles in motion.

TABLE 1. *Size-grade distribution of particles in transit across the dune*

Locality number	Distance from wet line	Size-grade distribution (per cent)					
		>1 mm	1–½ mm	½–¼ mm	¼–⅛ mm	⅛–1/16 mm	<1/16 mm
4	250 feet	1.9	23.4	40.9	19.8	10.9	3.1
5	435 feet	2.5	14.7	28.4	22.5	22.1	9.8
6	550 feet	0.5	2.6	35.6	34.5	23.2	3.6
7	700 feet	1.4	10.7	35.1	30.9	19.4	2.5
8	800 feet	0.0	0.4	10.4	47.8	37.3	4.1
9	940 feet	0.0	0.6	26.3	51.0	20.3	1.8

Size and shape analysis.—The "clay pellets" in transit across the active dune are of two distinct types; gray, dense, angular fragments of microscopic clay particles and irregular aggregates of loosely cemented quartz grains of silt and clay size adhering to a matrix of clay. The coarser fractions (above ⅛ mm) include approximately 60 per cent quartz aggregates and 40 per cent angular clay fragments. The finer fractions (below ⅛ mm) are composed dominantly of fine, clear angular quartz grains which appear to result from the breakdown of the aggregates during transportation. Both the clay fragments and the aggregates effervesce vigorously in dilute hydrochloric acid and readily disintegrate with the addition of water. Some evaporite crystals are found in fresh samples and samples exposed to moist air at room temperature grew a mat of salt crystals within a few days.

The largest clay pellets or granules in active transit at the front of the permanent clay dune (250 feet from the wet line) were between 1 and 2 mm in diameter. At 800 feet from the wet line, the largest pellets were retained on the 0.5 mm screen. Only dust in suspension was carried beyond the 1945 margin at 940 feet from the wet line. These results agree rather closely with observations by Chepil (1946) on diameter of soil particles in transit across cultivated fields and in newly formed drifts derived from these soils.

CLASSIFICATION OF THE CLAY DUNE

The clay dune would be a source-bordering lee dune according to the classification of Melton (1940). Many clay dunes are climbing dunes and owe their position to the presence of a cliff or bank which served to check their advance. Other clay dunes are of the isolated type formed on low bars or rift deltas of tidal flats. The

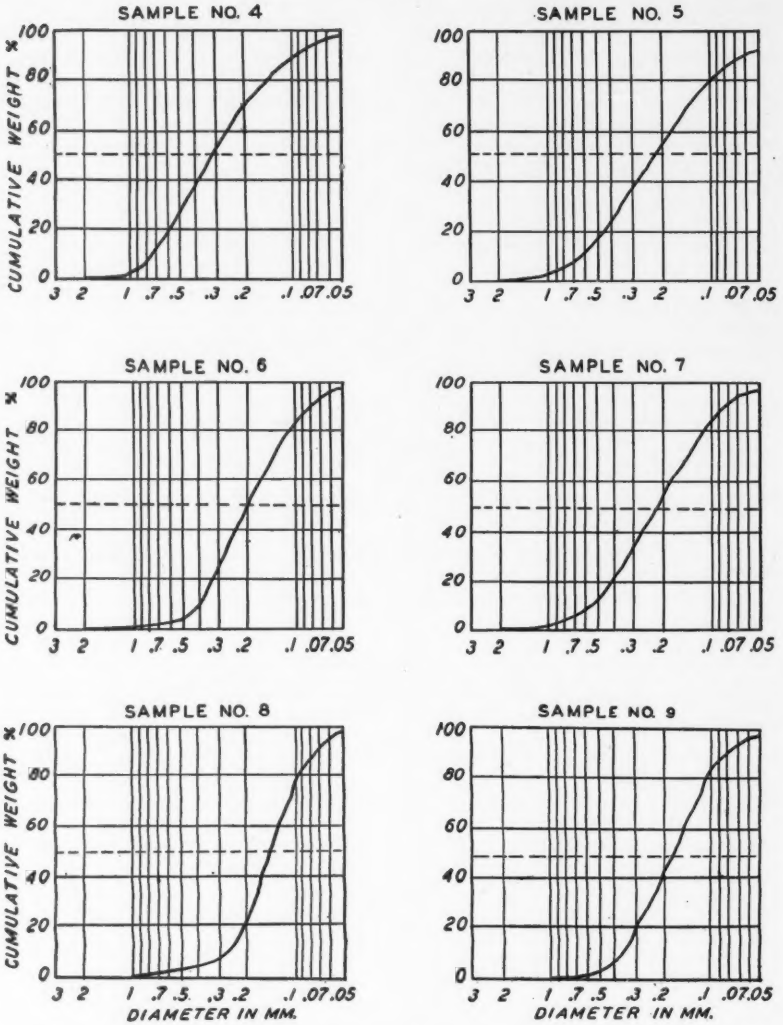

FIG. 9.—Cumulative-frequency curve for clay pellets in active transit across the clay dune, Oso Creek tidal flat southeast of Corpus Christi, Texas.

clay dune is stabilized by restored plasticity of the clay following addition of hygroscopic moisture from the atmosphere or by wetting action of rain. Shrub-coppice mounds form in the lee of vegetation on the front of the active dune; these are usually of less than dune rank and typically coalesce to become part of the larger, source-bordering feature.

ECONOMIC ASPECTS OF THE CLAY DUNE

Weathering of the clay dune produces a gray, drab, or light-brown clay soil which supports a vegetation consisting of mesquite, cactus, Spanish dagger, salt weed, and salt-resistant grasses. This type is of little or no agricultural value except for pasture. Where river courses have changed, bringing fresh waters to the former saline flats, adjacent clay dune soils have been leached and are now successfully farmed.

Real estate development south of Corpus Christi, Texas, in the vicinity of the clay dunes along the shore of Oso Creek estuary northwest of Ward Island has been seriously hampered by the large amounts of dust rising from the tidal flat and the active clay dune.

Recent attempts have been made to utilize the material from the clay dune ridges for the making of clay products.

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DECEMBER, 1949

SUPPLEMENT TO "RESULTS AND PROBLEMS OF HEAVY MINERAL ANALYSIS IN GERMANY: A REVIEW OF SEDIMENTARY-PETROLOGICAL PAPERS, 1936-1948"*

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1. INTRODUCTION

The University of Goettingen, with its famous Institute of Sedimentary Petrology (Correns, v. Engelhardt, Schumann, *et al.*), has played a large part in German heavy-mineral studies. Its director, Professor Correns, is the dean of German sedimentary petrologists.

2. METHODS

Correns (1941/42) does not divide the sedimentary samples into size fractions before separating the heavy minerals. This method, adopted by many petrologists, yields the whole crop of heavy minerals. The separation is carried out in a special separatory funnel (Scheidetrichter), and not by centrifuge. Separation by centrifuge is more rapid, but no more accurate. For mounting, Correns proposes piperine as a suitable medium because its index of refraction is greater than that of Canada balsam.

3. SELECTION OF GRAIN SIZES FOR HEAVY MINERAL ANALYSIS

Tröger (1940) has made a comparative study of mechanical analysis by sieving and by elutriation.

5a. RECENT

In a comparative study of mechanical and mineralogical composition of dune and water-carried sands, Engelhardt (1940) has found characteristic differences between these two types of sediments. The study was carried out in the Rostock region, Mecklenburgh (no. 3 on the map); grain diameters were measured microscopically. Thus it can be seen that the modal sizes of quartz are quite similar in the two types of sediment, but the modal size of garnet is significantly greater in the wind-blown material.

6(c). PLEISTOCENE (GLACIAL)

Fiedler (1939, 1940) has studied the boulder-clays of northwest Germany. Sediments of the Elster, Saale, and Weichsel glacial stages can be differentiated by heavy mineral analysis.

7(c). TERTIARY

Müller and Tröger (1948) have recently described the heavy-mineral content of the Oligocene Bavarian Molasse. The most conspicuous difference between the lower and upper Molasse is the content of epidote. In addition, in both the lower and upper Molasse there are regional variations between the Allgäu region and upper and lower Bavaria (nos. 16 and 24 on the map).

8. CRETACEOUS

Scheidhauer (1940) describes a remarkable example of heavy-mineral sorting from the upper Cretaceous sandstones of the Elbsandstein-Gebirge, near Dresden

* The material in this supplement was sent by Dr. Sindowski for incorporation in the original paper (this *Journal*, vol. 19, no. 1, pp. 3–25, 1949), but was lost in transit. In submitting it in the form of a supplement, the same numbering system for the various sections has been retained. For example, section 6(c) of this paper is supplementary to section 6(c), p. 12, of the original paper. Numbers of tables correspond in a similar manner.—Lincoln Dryden.

TABLE 2a. *Equivalent diameters in mm by sieving and elutriation (after Tröger 1940)*

By sieving	Quartz	Tourmaline	Zircon
	0.5	0.5	0.66
	0.2	0.2	0.265
	0.1	0.1	0.13
	0.05	0.05	0.066
By elutriation	**Quartz**	**Tourmaline**	**Zircon**
	0.5	0.42	0.27
	0.2	0.18	0.12
	0.1	0.09	0.066
	0.05	0.045	0.034

TABLE 13a. *Distribution of minerals in five samples of wind-blown and of water-transported sands (after Engelhardt 1940)*

Minerals	Most abundant (modal) size in mm									
	Wind-blown					Water-carried				
quartz	0.176	0.160	0.124	0.216	0.156	0.124	0.080	0.140	0.160	0.120
garnet	0.120	0.112	0.088	0.144	0.104	0.064	0.048	0.080	0.088	—
magnetite	0.088	—	—	0.104	—	—	—	0.064	—	0.056

TABLE 17a. *Mineral composition of boulder-clays of Elster, Saale, and Weichsel glacial stages, showing average frequencies of heavy minerals derived from Fennoscandia (after Fiedler 1939, 1940)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
garnet	39	20	18	38	34	25	28	20	26	19	29	27	37	28	40	30	35	30
epidote	25	31	44	21	19	33	32	40	32	44	37	26	26	25	22	26	17	20
hornblende	23	43	26	22	31	19	21	24	25	23	17	23	16	14	20	18	31	17

1, 2, and 3: Sleswick-Holstein, Weichsel, Saale, and Elster, respectively; 4, 5, 6: Berlin region, W., S., and E.; 7, 8: Hamburgh region, S. and E.; 9, 10: between Bremen and Hamburgh, S. and E.; 11: Heath of Lyneburgh, S.; 12: between Brunswick and Magdeburg, S.; 13, 14: foreland of Harz Mts., S. and E.; 15: Westphalia, S.; 16: Saxony, E.; 17: East Pommerania and East Prussia, W.; 18: Upper Silesia.

TABLE 24a. *Composition of the Molasse of Bavaria, showing vertical and horizontal differences in heavy-mineral content (after Müller and Tröger 1948)*

Mineral	Upper Molasse			Lower Molasse		
	1	2	3	1	2	3
tourmaline	2	8	4	2	9	9
zircon	8	6	1	14	5	62
rutile	5	2	1	8	5	1
garnet	44	36	18	56	72	19
staurolite	27	4	3	7	9	1
kyanite	2	1	1	—	1	—
hornblende	—	3	28	1	—	—
epidote	6	34	42	3	—	—

1: Allgäu region; 2: upper Bavaria; 3: lower Bavaria.

in Saxony. He studied the ratio of zircon and tourmaline in the fraction 0.1–0.05 mm and found that tourmaline is more abundant in this fraction in coarse sandstones, zircon more abundant in the fine ones. Other size fractions give similar results.

9. JURASSIC

Schumann (1944) supplements the earlier work of Deecke, and gives some new localities and results for the Cornbrash sandstones of northwest Germany.

10. TRIASSIC

The upper Keuper of northwest Germany is represented by the Rhaetic sandstones. Engelhardt (1942) studied their heavy-mineral content, and found three sources for the sedimentary materials. The Flechting Hills (no. 33 on the map) have yielded fine-grained tourmaline and zircon (often zoned); garnet is missing. The area south of Brunswick is the source of fine-grained tourmaline and zircon, admixed with colorless and reddish garnet. The third assemblage—yellow garnet, coarse-grained tourmaline, and zircon—has been derived from the region of the Harz Mountains, although the precise source-rocks of this assemblage are still unknown.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 19, NO. 3, PP. 131–134
FIGS. 1–4, DECEMBER, 1949

METHOD OF PRESERVING WET, FRAGILE GEOLOGIC SPECIMENS

MARION A. ARTHUR
Humble Oil & Refining Company, Houston, Texas

Throughout the geological profession and, particularly, in the oil industry, it is frequently necessary to preserve wet, friable, or otherwise fragile cores. One current technique for attempting this is described by Sawdon (1948). Clear plastic tubes of any desired diameter or length are used to contain cores, cuttings, etc. Caps for sealing the ends watertight are furnished, so that all specimens may be neatly encased and easily shipped. This is an excellent, low cost system for handling large quantities of specimens. But in many cases the sample cannot be studied inside the plastic tube due to obscuring by mud or loose particles and if removed from the tube cannot be handled easily or else becomes useless by drying out.

For such samples we have found an ideal way of embedding and preserving them is the use of the technique developed by Rohm & Haas Company (Hiltner, 1944) with minor changes. This technique is outlined as follows:

1. *Prepare object.* Avoid, if possible, any light materials such as wood or any inhibitive materials such as rubber. If the sample needs fastening or cementing, use acrylic cement or tie with nylon thread.

2. *Soak object.* Dip in a syrup made from 20 per cent polymer. The polymer recommended is Rohm & Haas' Plexiglas compression molding powder, formula 100-Y. The monomers used are ethyl methacrylate and methyl methacrylate, usually half and half. Increasing the percentage of ethyl decreases the brittleness but also decreases the clarity. About 80 per cent monomer in the syrup is correct. If very fragile, the object may be sprayed with an acrylic lacquer, such as Krylon. This step may be omitted in many cases. Whenever the specimen may disintegrate during step 4 below, the sprayed lacquer makes a useful surface binder.

3. *Mount object.* Or prepare a mount for it. The purpose is simply to suspend or hold the object in approximately the middle of the resin block. Therefore, the usual mount is a sheet of Plexiglas with an occasional side or edge wedge to fix the object in position. Use glass or iron molds.

4. *Prepare dough.* All doughs to date have been 35 per cent monomer plus 65 per cent polymer, as recommended by Rohm & Haas. The quantities needed are weighed out and mixed in a motor driven mixer. From 5 to 45 minutes are required, depending on the materials, and "ready" is signified by the dough becoming non-settling, viscous, and homogeneous. It must be poured within 20 minutes thereafter.

5. *Polymerization or cure.* Temperatures run from 52° C. to 62° C. and pressures from 60 to 175 psi. Times depend on the size of the block and the lag in oven heat. Generally, overnight works best.

6. *Annealing.* There is considerable influence exerted on the characteristics of the acrylic plastic by the cooling period. We have found it advisable for solid castings to run the autoclave up to forming temperature, or at least 90° C., and then cool slowly under pressure. Rohm & Haas recommends a cooling rate of 15° F. per hour.

Minimum equipment: Autoclave, mixer, nitrogen tank and regulator, miscellaneous molds, balance, raw materials, and lathe for polishing finished blocks.

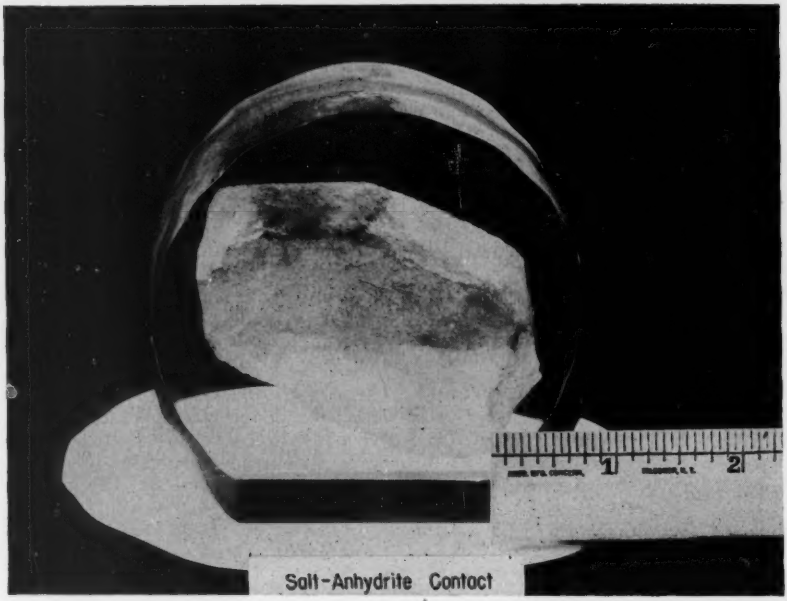

FIG. 1.—Mount of specimen showing salt-anhydrite contact.

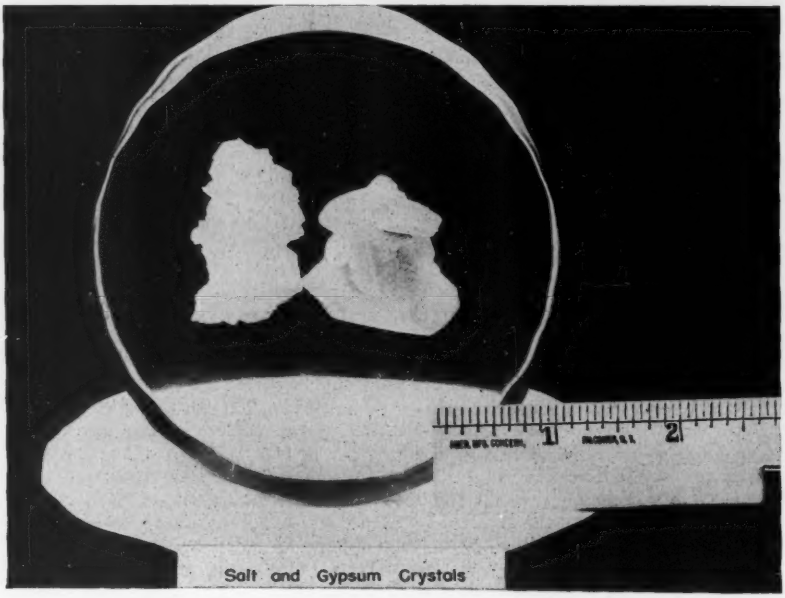

FIG. 2.—Mount of salt and gypsum crystals.

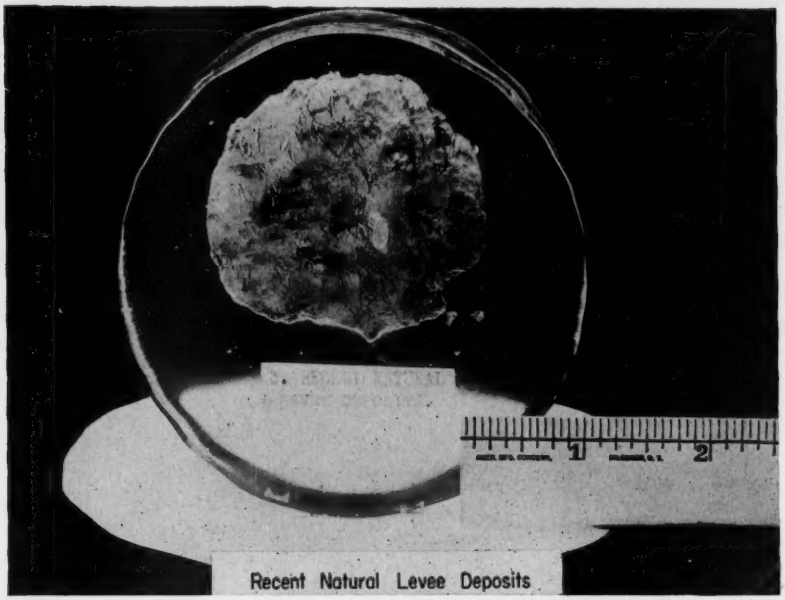

FIG. 3.—Mount of sample of natural levee deposit.

FIG. 4.—Mount of mastodon tooth.

Discussion: In Sando and in Strumia (1947) are described two other embedment techniques. In both, dehydration is required or prescribed, and both methods use a tedious layer-on-layer process. The system outlined above will handle in a single run any size of core in any depth of Plexiglas, limited only by the size of the autoclave.

The resulting castings, as illustrated in figures 1–4, are transparent, permanent, clean, odorless, and easily handled.

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DECEMBER, 1949

REVIEWS

Submarine Geology. By Francis P. Shepard. Pp. 348, figs. 106, 1 chart. Harper and Brothers, New York, 1948. Price, $6.00.

This book represents an important marker in the progress of earth science, inasmuch as it presents for the first time an integrated treatment of the ocean floor from a strictly geological point of view. Dr. Shepard's active participation in many of the advances in oceanography and submarine geology during the past two decades, and especially during the late war, place him in the front rank of authorities on the geology of the ocean floor. Many of the recent advances, plus earlier established principles, are embodied in the present volume.

The book is particularly interesting to sedimentary petrologists for the broad framework which it provides on principles of marine sedimentation, and the relations between sediment properties and conditions of accumulation. Following two introductory chapters, the author considers waves and currents, the classification of shores, and the movement of sand along coasts. Continental shelves, continental slopes, and submarine canyons comprise the succeeding three chapters, with considerable attention paid to the types of deposits found on or in these features. A chapter on coral reefs, one on the floor of the deep oceans, and a closing chapter on economic applications, complete the volume.

This brief recitation of chapter headings gives only a faint indication of the wealth of information contained in the volume. Of particular interest to sedimentary petrologists are the chapters on waves and currents, and on beaches and sand movement along the shores. These chapters embody recent advances in knowledge of rates of erosion, cyclical phenomena on beaches, depth of wave attack, and related topics of fundamental importance in understanding beach deposits. The treatment of continental shelves and continental slopes provides important information on the distribution of sediments on these features, and dispels earlier misconceptions regarding the gradation of sediments from coarse to fine seaward. An excellent discussion of the probable reasons for the observed somewhat irregular distribution of sediments is given in chapter 6. The chapter on coral reefs is noteworthy for the new facts which it presents, and its timely interest in the study of ancient coral reefs as oil reservoirs. The chapter on the floor of the deep oceans provides a wealth of data on deep-sea deposits, of particular interest in the interpretation of ancient sediments. In the reviewer's opinion, the problem of maximum water depths in geosynclines and in epeiric seas will be answered ultimately from detailed comparison of ancient and modern sediments; and here Shepard's data provide information on the recent counterpart.

These several items selected for comment were chosen to point out the significance of the volume to sedimentary petrologists, and they do not imply that the remaining topics are not of interest and importance. Certainly Shepard's chapter on submarine canyons is challenging in its treatment, and important in understanding geological processes. The book is indispensable in any geologist's library, and its clarity of style and excellent organization make the book particularly suitable as a text for special courses in submarine geology, as well as supplementary reading for more conventional courses in sedimentation.

W. C. KRUMBEIN

The Colloid Chemistry of the Silicate Minerals. By C. Edmund Marshall Pp. 181; figs. 85. Academic Press, Inc New York, 1949. Price, $5.80.

This little book is volume I of a series of monographs prepared under the auspices of the American Society of Agronomy. The author is Professor of Soils at

the University of Missouri and has devoted his own researches toward an elucidation of the colloid chemistry of the clay minerals. It is not surprising, therefore, that with the exception of a brief reference to the structure of silicates in general and a short chapter on the colloid properties of the zeolites, the book is entirely concerned with the clay minerals.

The author begins with a presentation of the structure of the silicates and then proceeds to a discussion of the size and shape of clay particles; the optical properties of clay suspensions, ionic exchange reactions, the electrokinetic properties of clay suspension; the mechanical properties of clay suspensions, sols, and pastes; the properties of clay aggregates and films, and some other properties. Very wisely, the consideration of these properties is restricted to evidence gained from the study of reasonably pure clay mineral material. In the presentation the aim is to clarify fundamentals, and the myriad of applications in other sciences or to technology are not considered.

In the brief space of the book it has been impossible to consider all the diverse theories advanced to explain the various colloidal properties of the clay minerals. The author has had to make a selection of theories, and unfortunately alternative theories which appear more satisfactory to other workers in the field are frequently given scant attention. For example, it is to be regretted that more attention was not given, in the explanation of many clay-water properties, to the implications of the concept of the orientations of the water molecules in the adsorbed water adjacent to some of the clay mineral surfaces.

Frequently a matter is considered without giving sufficient detail for those who are not completely familiar with the original publications. In such cases the reader may be annoyed to find that the original workers are named but no reference is given to their publications.

The book is quite free from errors. However, there is a particularly regrettable one that is repeated many times. The structure of the highly hydrated form of halloysite (Endellite of some American workers, Halloysite of European workers) is stated to be an alternation of kaolinite layers and double water layers. Actually it is generally accepted that the structure of this mineral is an alternation of kaolinite layers and single water layers. Unfortunately, the author in some instances proceeds to theorize on the basis of the erroneous structure.

Professor Marshall has performed a very valuable service to all students of clay materials by assembling and critically considering a vast amount of the existing data concerned with the properties of clay minerals and the theories advanced to explore them. The book will be a necessary addition to the library of all serious students of clay materials.

R. E. GRIM

JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 19, NO. 3, PP. 137–138
DECEMBER, 1949

ANNOUNCEMENTS

JOINT ANNUAL MEETING

Stevens Hotel, Chicago,
April 24–27, 1950

The annual meeting of the S.E.P.M. will be held at the Stevens Hotel, Chicago, on April 24, 25, 26, and 27, 1950. As in previous years the meeting will be held jointly with the A.A.P.G. and S.E.G.

S.E.P.M. TECHNICAL PROGRAM

In addition to presidential addresses and joint sessions with the other two exploratory societies, the S.E.P.M. program will include technical sessions and a symposium. The symposium, under the direction of the Research Committee, will be on Problems in Marine Geology and will include papers by outstanding authorities.

President Stenzel has appointed L. L. Sloss, Northwestern University, Evanston, Illinois, to be program chairman for the S.E.P.M. Members planning to submit papers should notify the program chairman by January 1st of the title and length of their papers. Abstracts, typewritten, double-spaced, and in duplicate, are due on or before February 1st.

THIRD WORLD PETROLEUM CONGRESS

The organization of a congress like the Third World Petroleum Congress, to be held in The Hague, Holland, from 28th May to 6th June 1951, requires much internal planning before the full details can be placed before the public.

It is, therefore, with much pleasure that we can now give some further details of the organization of this congress, which we expect, will be the most important post-war gathering of the world's oil experts.

It will be remembered that on two occasions a World Petroleum Congress has been held, the first in London in 1934, the second in Paris in 1937. The initiative for these congresses was taken by a Permanent Council composed of delegates from several countries. The present Permanent Council will be composed of delegates from the U.S.A., Great Britain, France, Canada, Venezuela, Belgium, and the Netherlands. The chairman is Colonel Louis Pineau of Paris, the secretary Mr. D. A. Hough of London.

In May 1949 this Council decided to hold the Third World Petroleum Congress. Its organization was first offered to representatives of the U.S.A. who declined, however, in view of the fact that the U.S.A. is already entertaining many congresses in this field. The Council thereupon resolved that this Third Congress should take place in the Netherlands.

The Petroleum Section of the Netherlands Royal Institute of Engineers in The Hague was invited to organize the Congress. They accepted this invitation after securing the support of the Netherlands oil industry. As a consequence the "Organizing Committee of the Third World Petroleum Congress" was formed with Mr. G. A. Tuyl Schuitemaker as chairman, treasurer Mr. J. A. Beukers and secretary Mr. J. W. Zwartsenberg (30, Carel van Bylandtlaan, The Hague).

The congress will be held in The Hague-Scheveningen, commencing on 28th May, 1951, and will last up to 6th June. The members of the congress will be accommodated at the main hotels in The Hague-Scheveningen. The sessions of the various sections of the congress will be held in three halls of the Kurhaus Hotel.

National committees are being formed in each country to invite, collect and screen reports from their country. These

reports (each accompanied by a summary) will finally be forwarded to the Organizing Committee in the Netherlands. The official languages at the congress will be English and French and all reports have to be submitted in one of these languages or in both. It is intended to send preprints of the reports to Members of the Congress before 1st March, 1951.

The purpose of the Congress will be to focus attention on the present position of science and technique in the petroleum industry. In principle there will be ten master sections at the Congress:

1. Geology, Geophysics, Geochemistry;
2. Drilling and Oil Production;
3. Physical Technology;
4. Oil processes involving chemical conversions;
5. Production of chemicals from petroleum, their properties and applications;
6. Measurement and Control, Testing, Chemical Analysis;
7. Utilization of oil products;
8. Construction of equipment, materials, corrosion;
9. Transport, storage, distribution;
10. Economics, statistics, documentation.

These sections will discuss papers submitted by petroleum experts of international standing. The General Reporter of a given section will read abstracts from the papers under consideration, and suggest topics for discussion. These discussions and the conclusions reached will also be published in the Proceedings of the Congress.

Those taking part in the Congress will find an opportunity of studying the Netherlands—not only by excursions to its petroleum and other industries, but also by tourist trips to typical Dutch towns and rural districts. A ladies' committee will arrange for the reception and entertainment of lady visitors during their stay in the Netherlands. A pamphlet, giving full particulars, will be available in the beginning of 1950.

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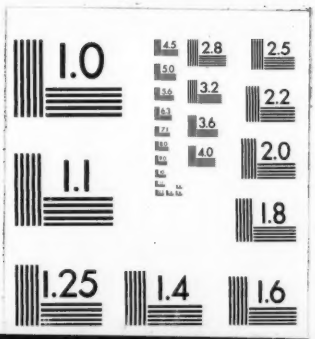
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